

Participatory Plant Breeding Methods for Organic Cereals

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Abstract

Formal breeding methods were not always suitable to address the very large diversity of both environmental conditions and end-user needs. Both were frequently encountered either in marginal areas of developing countries or in organic farms of EEC. Participatory plant breeding (PPB) methods represent alternatives aimed to improve local adaptation breeding, to promote genetic diversity, to empower farmers and rural communities. The term PPB refers to a set of breeding methods usually distinguished by the objectives (functional or process approach), institutional context (farmer-led or formal-led), forms of interaction between farmers and breeders (consultative, collaborative or collegial), location of breeding (centralized or decentralized), stage of farmers participation in the breeding scheme (participatory varietal selection or participatory plant breeding)...

Among all these methods, the best strategies for organic breeding and their impacts on breeding techniques are discussed. A PPB program actually conducted at INRA – Montpellier (F), involves the whole organic durum wheat interprofessional organization, from farmers to consumers. It is used to assess the interest of a multidisciplinary approach and to discuss the role of each participant in such program. Must participation be seen as a means towards an end or an end in itself?

Keywords

Participatory Plant Breeding- Organic Breeding- Genotype x Environment Interaction- On-farm trials- Durum wheat

Introduction : Why formal breeding methods are not always suitable?

Organic production in European countries shows great similarities with production in marginal areas in developing countries, such as (i) heterogeneous environment, (ii) large diversity of farmer's needs, (iii) lack of adapted varieties, (iv) disinterest of formal seed sector. Facing such diversity and heterogeneity, conventional plant breeding often fails to meet the needs of farmers and to develop cultivars showing specific or local adaptation.

Professional breeders, often working in relative isolation from farmers, have sometimes been unaware of the multitude of preferences — beyond yield, and resistance to diseases and pests — of their target farmers. Ease of harvest and storage, taste and cooking qualities, crop maturity speed, suitability of crop residues as livestock feed ...are just a sample of farmers' criteria difficult to grasp in a conventional breeding scheme. In Peru, for example, the PRGA plant breeding working group compiled an inventory of almost 40 different traits interesting farmers for evaluating potatoes (CIAT, 2000). Without close discussions with end-users and observations of their agricultural and social practices, breeders are unable to imagine or anticipate their necessary needs. During their professional training, plant breeders have little exposure to survey/methods needed to elicit structured feedback from farmers (Morris & Bellon, 2004). Moreover organic farmers have to deal with several limiting factors and high heterogeneity that they could not uniformize with inputs; therefore they are looking for specific ideotypes according to their own use and cultural practices.

Formal breeding programmes can be briefly described as a centralized sequential process in which breeders collect germplasm, evaluate it under carefully controlled experimental stations, and make crosses among superior materials. The large amount of genetic variability continuously created is then drastically reduced through selection and surviving lines are spread among farmers. The process has been effective for farming systems sufficiently similar to those on experiment stations (Sperling et al., 1993) but not adapted when GxE interactions are large.

Formal breeding tends to focus on "broad adaptability" — the capacity of a plant to produce a high average yield over a wide range of growing environments and years. Therefore, candidate genetic material that yields well in one growing zone, but less in another, is quickly eliminated from the breeder's gene pool (Cecarelli, 1997). Yet, this "specific adaptability" may be exactly what organic farmers require and aims to increase agricultural diversity (Vernooy, 2003).

Facing difficulties to target environment conditions well and register all end-users needs, to translate them into criteria of selection and to build an ideotype, breeders begin to be interested by participatory plant breeding (PPB) defined as end-users' participation in selection process. It appears to be a suitable alternative to match up to organic agriculture expectations.

PPB: A single term but different approaches- A review

Participatory plant breeding is a relatively recent concept. Indeed, first scientific papers on this subject appeared 10 years ago. But already it refers to a large set of approaches and breeding methods. All these approaches could be integrated into an n-dimension matrix where the following items would be crossed:

1- The objectives

PPB mixes usually 2 types of approaches: Functional and Process, which are defined by Thro & Spilane (2000). **Functional approach** consists of getting better adapted crop varieties i.e. more closely tailored to small-scale farmers' needs, whereas, **process approach** aims to empower farmers to develop their skills as plant breeders. Belonging to these 2 types, some current PPB objectives are detailed below

- ***Getting adapted materials***

This objective is more often mentioned in the literature as: "speeding up the transfer of cultivars and their adoption". Although relatively little empirical work has been done to document the speed of PPB compared to conventional breeding, recently evidence has started to emerge suggesting that PPB can lead to earlier adoption of modern varieties, with no major additional costs (Witcombe et al., 2003). But negative connotation can also be linked to this aim: indeed, it may assume that cultivars are already created by breeders and PPB appears as an opportunity to speed up the adoption by farmers. Setting out clearly the objective permits an assessment of whether the project considers farmers as a simple consumer or as a partner. The first consideration is out of place in PPB projects.

- ***Improving local adaptation***

Breeding for specific adaptation is a more sustainable strategy than breeding cultivars that can only express their superiority at high level of inputs (Ceccarelli, 1996). Local adaptation contributes to limit genetic erosion and therefore to avoid major risks due to varietal homogeneity on the territorial scale. Breeding for marginal or organic environments shall include selection of parents and segregating populations in environments similar to farmers' conditions.

- ***Promoting genetic diversity***

Breeding for specific adaptation to organic environments implies a re-evaluation of the role of genetic resources such as landraces. In European countries, landraces are unfortunately no longer cultivated. They possess adaptative features and represent a gene cistern that can be really useful for organic environments. Biodiversity which is so important for organic farmers justifies the choice to breed for specific adaptation. Associating end-users with evaluation and management of genetic resources is one important objective. PPB methods, in encouraging the maintenance of diverse locally adapted populations and in-situ conservation of crop genetic resources, enhance genetic diversity.

- ***Empowering farmers***

PPB may aim to empower farmers i.e. to bolster their autonomy or to increase their freedom to choose varieties. It allows rural communities to maintain genetic resources they value and enables them to participate in the development of new varieties that suit their needs. PPB methods thus can empower groups that traditionally have been left out of the development process (Mc Guire et al., 1999).

2- Institutional context

According to the leader or to the initiator of the project, it is used to differentiate a **formal-led PPB** program which is initiated by researchers inviting farmers to join breeding research, from a **farmer-led PPB** program, where scientists seek to support farmer's own systems of breeding, varietal selection, and seed multiplication and dissemination. Based on the work of Franzel et al. (2001), a more elaborated differentiation can be proposed by identifying leaders of breeding process designs and those of management.

3-Forms of Interaction between actors

The various modes of participation can be thought of as points along a continuum representing different levels of interaction. Each mode of participation can be characterized in terms of how farmers and plant breeders interact to set objectives, take decisions, share responsibility for decision making and implementation, and generate products (Morris & Bellon, 2004). In practice, three kinds of participation are usually distinguished: **consultative** (information sharing), **collaborative** (task sharing), and **collegial** (sharing responsibility, decision making, and accountability) (Sperling et al., 2001).

4- *Location of selection*

Decentralized selection, defined as selection in the target environment, has been used to emphasize favorable GxE interactions. It is a powerful methodology to fit crops to the physical environment and to the crop system. However, crop breeding based on decentralized selection can miss its objectives if it does not utilize the farmers' knowledge of the crop and the environment, because, it may fail to fit crops to the specific needs and uses of farmers communities.

PPB can also be held in **centralized** research stations. Farmers are therefore invited to visit and practice selection of lines grown at experimental stations.

5- *Stage of selection*

Each plant breeding project includes the following stages:

1. Setting breeding objectives
2. Generating genetic variability (from collection or farmers' fields and/or through crossing)
3. Selecting among variable materials
4. Evaluating experimental varieties
5. Multiplying and disseminating seed

In many cases, farmers' participation is limited to the final steps: evaluating and commenting on few near-finished or advanced varieties just prior to their official release. It is known as **participatory varietal selection** (PVS), while **participatory plant breeding** (PPB) concerns participatory selection within unfinished or segregating material i.e. with a high degree of genetic variability (Witcombe et al., 1996). Both terms are included in the **participatory crop improvement** (PCI) concept.

PVS can be useful before beginning a PPB process because it helps to identify both parents and important target traits. Usually, PPB program used only a few crosses from which large populations were produced (Witcombe & Virk, 2001) and because few parents are employed, their choice is crucial. Very few programs, even in PPB, imply farmers in the first three stages. However, many of the varieties reaching on-farm trials would have been eliminated from testing years earlier if farmers had been given the chance to critically assess them (G.Toomey, 1999).

This bibliographic review emphasizes the great diversity of PPB approaches. However, all have in common the aim of shifting the locus of plant genetic improvement research towards the local level by directly involving the end user in the breeding process (Morris & Bellon, 2004).

Interest of Participatory Plant Breeding for organic conditions

Most PPB projects are initiated by international institutes of research and aim to speed up the adoption of cultivars by small farmers in developing countries. Up to now, these projects are essentially built around the implication of farmers in selection processes.

Very few PPB projects are conducted in European countries and they concern essentially organic agriculture (for more details, visit the web site: <http://selection-participative.cirad.fr/>).

This is not surprising. As mentioned in the introduction, organic production shows great similarities with production in marginal area in developing countries, such as heterogeneous environment, large diversity of farmer's needs, lack of adapted varieties and disinterest of the formal seed sector.

Variability of organic farming systems is so high that developing a variety fitting to fit all situations is not conceivable. Because they are aware of the breeding cost necessary to meet several objectives and also to develop several locally adapted varieties, private breeding companies doesn't want to join in the organic seeds market. But, considering an approach like PPB, we can imagine, without additional costs, developing varieties adapted to an area, a region, a specific environment and why not at the farmer field scale?

For these reasons, PPB appears to be a more suitable solution for organic conditions than formal breeding.

Moreover, compared to conventional breeding, PPB seems to be the best alternative to fit the principle aims of organic agriculture for production and processing prescribed by IFOAM, and especially: "(i) to maintain and conserve genetic diversity through attention to on-farm management of genetic resources, (ii) to recognise the importance of, and protect and learn from, indigenous knowledge and traditional farming systems".

Indeed, because breeding for organic conditions means breeding for sustainability, the process of breeding is as important as the results. Therefore, breeding process must comply with the three following criteria for organic production: closed production cycles, natural self-regulation and agro-biodiversity. According to Lammerts van Bueren et al. (1999), equivalent criteria at the socio-economic level are: close interaction between farmers, trade, industry and breeders; regulations geared to organic agriculture and cultural diversity. Yet, PPB can be exactly defined by these words.

Participatory Plant Breeding of durum wheat: an INRA pilot project

Context- Objectives

The French organic durum wheat professional organization is sufficiently small-scale and closely integrated enough to be considered as a model. Indeed, organic durum wheat producers are located in two main territories in the south of France and regrouped into organic farmer's organizations, traders, seeds collectors and pasta processing industrialists are very few, and no breeding private company is interested by the organic sector. For consumers, durum wheat is a food product profiting from a healthy and environment friendly image.

The PPB program, initiated in 2001 at INRA- Montpellier (F) was based on a demand of organic farmers and pasta industrialists. The quality of durum wheat produced in organic conditions doesn't meet the requirements of the process industry. Indeed, no less than 15 criteria are required to transform the grain into semolina or pasta. Among them, the most important is the protein level. Under organic conditions and especially when nitrogen is limiting, durum wheat seed becomes un-vitreous like bread wheat seed and prevents the production of semolina. Such unsuitability puts the whole organic durum wheat organization into question, and poses the problem of its durability.

To identify the main causes, a multidisciplinary public research team, associating plant breeders, soil scientists, ecologists, agronomists, economists and sociologists was requested and decided to work in close collaboration with professionals. The action-research program is built around thematic activities in relevant domains and concerns the two main French territories of durum wheat production: Camargue and Pays Cathare (Desclaux et al., 2002). These territories can be mainly differentiated by the existence of animal rearing, the soil salinity, the organic farming systems. First investigations showed rapidly the lack of adapted varieties to limiting nitrogen conditions very frequent in the studied organic crop systems. Indeed, all available durum wheat cultivars came from breeding programs managed under conventional growing systems, with no nitrogen limitations. The need to begin a breeding programme in organic conditions was followed by thoughts about the best way to interact during this programme.

Different ways of participation and interaction between actors

In this project, which aims to boost interactions between actors, different forms and locations of participation and interactions are sought.

- Meetings

Preliminary meetings were organized to define the objectives of breeding and the main criteria. Each actor from farmers to consumers is invited to formulate his ideotype. A multidisciplinary team of researchers leads to a wider identification and understanding of the claims of all professional partners. For example, identification and evaluation of subjective traits as taste, aroma, appearance, texture... requires close collaboration between plant breeders, social scientists, farmers, process industrialists, consumers. Such subjective traits are difficult to measure quantitatively and belong to the register of human perceptions that social scientists help to identify. Formal durum wheat breeding has never focused on these traits and some were "contrary-bred".

- Surveys

A large written survey, containing questions about crop system and farmers' preferences, was carried out to catch the opinion of a great number of organic farmers in the two territories. Diffusion of such a survey was facilitated by the regional farmer's organizations that possess an exhaustive file of durum wheat producers in these areas.

Formulation of durum wheat ideotypes was much more different between territories than within. In the Camargue, existence of bull and sheep rearing brings natural nitrogen available for wheat during the vegetative period, but not during the period of seed quality elaboration. Farmers are looking for varieties efficient in the remobilisation of nitrogen from its vegetative parts. In Pays Cathare, nitrogen is limiting even during the first vegetative period and weed infestation is regularly high; the requested variety must have an important root system, and be able to compete with weeds and to draw nutrients efficiently.

- Informal discussions during field visits

Regularly and at least during flowering and at physiological maturity, field visits were organized. It's a opportunity for farmers, industrialists and researchers to discuss in concrete terms in front of genetic diversity. During such visits, all the actors are invited to express orally their opinion and also to write some notations according to a grid drawn up by breeders on the base of preliminary meetings and discussions with other actors. Regularly, this grid is improved. Visits were held both in farmer's fields and in the experimental stations. In the stations, important genetic resources and germplasm collection afford a large diversity of morphologic characters and therefore give rise to new questions leading to ideotypes inconceivable until then.

- Learning

Organic farmers are aware of genetic diversity maintenance and are used to grow several species, several varieties and several heterogeneous varietal structures (populations or mixtures). Such heterogeneity aims to maximise adaptability more for temporal scale than for spatial scale. In order to manage this diversity and not only maintain it, the biology (reproduction type, ...) of cultivated species must be well known. Farmers ask for training on these subjects. On the other hand, the great expertise and observation capacity of farmers are recognized by all the actors. Complementary knowledge leads to dynamic in situ conservation and to the adaptation of a portfolio of varieties.

- On-farm trials experimentation

From the beginning of the project, some farmers desired to experiment old varieties, which were the first durum wheat cvs introduced or bred in France 50 years ago. Others farmers asked for populations. We complied with their request and provided them with additional segregating or advanced pure lines and populations resulting from crosses between durum wheat and emmer or wild species. Such tetraploid relative species (*T.t.dicccoides*, *T.t.dicccum*, *T.t.polonicum*...) are expected to bring interesting characters of quality and adaptability. Some pure wild accessions were added in the field.

The main aim of such on-farm and participatory breeding is to approach farmer's preferences and to better target environmental conditions by increasing and managing genetic variability. Due to low available seeds quantity, the farmer's network was limited to 7 locations. In each farmer's field, the experimental design was a randomized complete block with replications. Sowing and harvesting of experimental plots (10m²) require specific experimental materials and are also carried out by the research institute. To pass round these constraints that prevent to approach totally the farmers' management practices, some lines preliminary multiplied, are sown directly by the farmers. A mother-baby design is used for advanced materials.

On-farm selection is conducted not only on farmer's fields but also with farmers. The farmer is implicated in growing and letting evolve plants in his environment. According to the type of materials (genetic resources, segregating pure lines, populations or advanced materials), the farmer can be in a position to innovate, to adapt or to manage dynamically. He gets the possibility to clarify his preferences or reject criteria more freely than in front of a researcher or his peers. He can assume the right to maintain one cultivar and/or create mixtures. Observations of his choices produce much more information than any survey could, about suitable varietal structures and also ideotypes.

The stage of the breeding process at which farmers are involved depend on the type of materials. Agronomic behaviour examination of genetic resources is a preliminary to the early step of the breeding scheme: "Generating genetic variability". Owing to their unique knowledge of existing varieties, it is really pertinent to involve farmers in the observation and selection of genetic resources. The following steps, selection and evaluation, are done in close collaboration between farmers and breeders and concern respectively segregating lines or populations and near-finished or finished varieties.

Yield and agronomic behaviour data are compiled and analyzed by researchers and diverse criteria of seed quality are measured by industrialists.... Results are discussed between all actors and this work of synthesis creates opportunity for feedback and may lead to a re-examination of the first step of the breeding scheme which is 'setting the objectives'.

PPB provides all the actors with the opportunity to assess genotype-by-environment interactions. Most often, environment is only defined by climate and soil data. For example, unfavourable environments are defined by Cecaelli (1996) as those where crop yields are commonly low due to the concomitant effects of several abiotic and biotic stresses. The definition of environments plays a key role in determining breeding strategies. Therefore, we emphasize the consideration of the whole acceptance of environment, including not only physical environment but also socio-economic environment. Both are completely integrated into farmer's management practices that agronomists and social scientists investigate. Strategies of conversion to organic farming and management systems are strongly correlated to farmer motivation. In the project, two extreme types have been identified: (i) pioneers, motivated for ethical reasons and first converted to organic farming, include a high diversity of species in their crop rotations and crop cultivation practices are relatively stabilised, (ii) the newly converted, for whom recent conversion can be seen as a timely strategy to counter difficulties in the formal sector, choose mixed cropping systems (organic and conventional) to limit risks related to a technical and/or economic failure of the organic production system. On these farms, crop cultivation systems are not stabilised, crop rotations little established and cultivation practices, while respecting organic specifications, refer to conventional practices (Mouret et al., 2004).

Approaching such a level of knowledge of the broad sense of environment leads to a better mastering of breeding targets.

Discussion/Conclusion

Most often in the literature, PPB methods are presented as the interaction between farmers and breeders. The organic durum wheat project wants to emphasize the interest of opening the interaction to other professional partners and other researchers from relevant disciplines. Convening the whole of the professional organizations leads to the emergence of new breeding criteria and to a better knowledge and understanding between actors (farmers and industrialists especially).

In organic conditions, diversity of physical location, limiting factors and farming systems is so high, that agronomists are a great help for breeders to better characterize each environment. As the same farming systems are related to social criteria, sociologists may identify them in order to better seize farmers needs and therefore better target suitable varieties.

But participatory plant breeding can not be limited to studies conducted for a limited period of time to document indigenous knowledge and farmers' preferences. To be effective, participation should become a permanent feature of plant breeding programs concerning crops grown in agriculturally difficult and environmentally challenging environments.

The project may be defined as a mix of different objectives: getting adapted materials by improving local adaptation, promoting genetic diversity and empowering farmers. It is neither a farmer-led program nor a formal-led program but really a whole professional organisation and researchers-led program. The form of interaction is collegial. Decentralized design is used and the principle is to conceive farmer's participation during the 3 first steps of the breeding scheme in order to better respond to sustainability stakes of organic agriculture. This represents a major rupture with regard to formal breeding schemes.

Discussion about more participation is interesting. "More participation is not necessarily better. Participation should be seen as a means to an end." (Morris & Bellon, 2003). But, PPB must not be reduced as 'farmer assisted selection'. The farmers involved in our project, assert the right to be considered as true partners of the breeding programme and not only as variety consumers or end-users. For involving researchers the participation of actors can either (i) be a means towards an end or (ii) an end in itself.

"Close collaboration between the parties is a must if they are to overcome possible conflicts of interests and agree on a set of breeding goals. An interactive approach to breeding may provide that intensity of collaboration which is so crucial to organic agriculture" (Lammerts van Bueren et al., 1999).

For practical and ethical reasons, organic breeding justifies the implication of farmers and end-users in a PPB program.

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